Iowa State Highway Commission
Materials Department
Special Investigations

[redacted]

REPORT OF R - 226A

ROAD METER

Modifications & Improvements

January 30, 1970

IOWA STATE HIGHWAY COMMISSION

Materials Department

Special Investigations Section

Report of 226A

Road Meter Modifications & Improvements

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by

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and

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1.0 INTRODUCTION

The Present Serviceability Index concept was developed at the American Association of State Highway Officials (AASHO) Road Test of 1958-1960.[1] It is an indicator of the ability of a pavement to serve the traveling public and used for an objective method of highway evaluation.

The Present Serviceability Index System is used to determine pavement performance levels with a numerical scale (AASHO) ranging from zero to five, and designated as follows:

PSI	Rating
4-5	Very good
3-4	Good
2-3	Fair
1-2	Poor
0-1	Very poor

The Bureau of Public Roads has another similar scale[4] with the following designations, and is perhaps more realistic in the evaluation of new pavement:

PSI	Rating
Above 4.5	Outstanding
4.5 - 4.1	Excellent
4.1 - 3.7	Good
3.7 - 3.3	Fair
Below 3.3	Poor

The serviceability index is a function primarily of longitudinal and transverse profile. The Present Serviceability Index takes into consideration the smoothness, cracking, patching and rutting. The longitudinal profile is summarized by means of rut depth, variance of transverse profile, etc.

The AASHO Road Test outlined the mathematical equation of the Present Serviceability Index in Highway Research Board Bulletin Number 250.

For Flexible Pavement

$$PSI = 5.03 - 1.91 \log(1+\overline{sv}) - 1.38rd^2 - 0.01 \sqrt{c_1+p} \quad (1)$$

For Rigid Pavement

$$PSI = 5.41 - 1.80 \log(1+\overline{sv}) - 0.09 \sqrt{c_2+p} \quad (2)$$

[1] AASHO Road Test, "Pavement Serviceability and Performance", HRB Special Report 61E (1962).

[4] Brua, Philip R., "Pavement Performance Information", Technical Bulletin No. 4, American Concrete Paving Association (1969).

where: $\overline{sv}$ = slope variance measured by AASHO Road Profilometer

c_1 = cracked area in square feet per 1,000 sq. ft. of pavement surface

c_2 = lineal feet of crack per 1,000 sq. ft. of pavement surface

p = square feet of patching per 1,000 sq. ft. of pavement surface

$\overline{rd}$ = average rut depth in inches at deepest part of rut.

The term Slope Variance ($\overline{sv}$) represents the longitudinal profile of the pavement.

A mathematical expression of Slope Variance measured by Chloe Profilometer outlined on page 136, Highway Research Board, Special Report 73, is:

$$\overline{sv} = 8.46 \left[\frac{\sum_{i=1}^{N} Y_i^2}{N} - \frac{\left(\sum_{i=1}^{N} Y_i\right)^2}{N} \right] - 3$$

in which

Y_i = counter value which is related to slope of the pavement

N = number of counts

$$\text{Chloe sv} = 8.46 \left[\frac{\sum_{i=1}^{N} Y_i^2}{N} - \frac{\left(\sum_{i=1}^{N} Y_i\right)^2}{N} \right]$$

The Chloe Profilometer[2], an electro-mechanical device, was developed at the AASHO Road Test. The slope is sampled at 6 inch intervals along the pavement wheelpath. The statistical slope variance is calculated and the Present Serviceability Index obtained. This device was designed to operate at a speed of less than 5 mph.

In 1965, a Portland Cement Association (P.C.A.) engineer developed a device known as the P.C.A. Road Meter.[3,4] The Road Meter is a simple electro-mechanical device of durable construction, which can perform consistently with extremely low maintenance. When this unit is installed in a conventional passenger automobile, tests can be made by the driver, without the need for traffic protection, at a speed of 50 mph or higher if required by the traffic stream. The development and theory of the Road Meter are described in Appendix 1 and 2.

[2] Carey, W.N., Jr., Huckins, H.C. and Leathers, R.C., "Slope Variance as a Measure of Roughness and the Chloe Profilometer". HRB Special Report 73, (1962)

[3] Brokaw, M.P., "Development of the P.C.A. Road Meter, A Rapid Method for Measuring Slope Variance", Portland Cement Association (1966)

[4] Brua, Philip R., "Pavement Performance Information", Technical Bulletin No. 4, American Concrete Paving Association (1969)

The Iowa State Highway Commission constructed a P.C.A. type Road Meter (Table II and III) in 1967[5] with slight differences from the original P.C.A. Road Meter. The Iowa State Highway Commission Road Meter has been used since 1968 for evaluating the rideability of state highways. In both 1968 and 1969, all primary roads (approximately 9000 miles) were tested in both directions. The Iowa State Highway Commission Road Meter equipment is continually being modified and improved (Table I).

2.0 PURPOSE

The purpose of this report is to discuss improvements in Road Meter equipment and testing.

3.0 EQUIPMENT

The Road Meter device (Fig. 1 to 6) consists of a flexible steel strand connected to the top center of the rear axle housing in the vehicle. The steel strand extends vertically through the trunk compartment and then through a small hole in the package deck just back of the rear seat. At this point, the strand passes over a transverse-mounted pulley, and is restrained by a tension spring attached to a small post on the package deck at a point near the right side of the body shell. Thus, vertical movement between the rear axle housing and the package deck is translated to horizontal movement of the strand.

Midway between the pulley and the tension spring, a roller micro-switch is attached to the metal strand. The switch is mounted in a small rectangular roller contactor slide plate that moves in transverse guides.

The micro-switch roller impinges on a segmented contact board constructed so that transverse roller movements can be measured in 1/8 inch increments, either plus or minus, from a reference standing position of the automobile. As the roller passes over each increment of the segmented contact board, it sends impulses to visual indicators and electric counters. The visual indicators are used to make sure the unit is operating correctly. The electric counters sum the number of impulses received from each of the increments of the segmented contact board, according to the magnitude relative to road-car deviations.

Through continual testing, various changes in materials and procedures have been evaluated. They are described as follows:

[5] Bunnag, Anuphan, "Iowa State Highway Commission's P.C.A. Type Road Meter", (1967).

1. Flexible Steel Strand

The Road Meters were first designed using 45 lb. test steel core fish leaders for the flexible steel strand. Later this was changed to 60 lb. test steel core fish leaders, when it was found that there was too much breakage. Even the 60 lb. test leaders did not solve this problem. Nylon covered (240 lb. test) aircraft cable is presently being used with satisfactory results; there has been no breakage of the aircraft cable. Some agencies have used a swivel bead chain for the flexible steel strand.

2. Roller Contactor Slide Plate

Originally, the roller contactor slide plate (Fig. 6) was constructed using two pieces of formica with the non-finished surfaces glued together. After some testing, these plates exhibited considerable wear from the track. Then being in a worn and rough condition, the plate would bind in the slides. Bakelite and plexiglass were used with very similar results. All were felt to be unsatisfactory.

Glass reinforced delrin was tried with excellent results. There was much less wear and the frictional resistance was greatly reduced, resulting in less tendency to bind in the slides.

3. Segmented Contact Board

The segmented contact board (Fig. 6) was constructed by glueing a strip of phospher bronze to a formica board and then cutting the bronze into 1/8" segments. This board was then glued to a plexiglass backing to give rigidity. This has worked quite well, but these boards have warped and when it gets cold they bind in the lower track. It is then impossible to zero properly and it causes abuse of the vernier dial.

Only recently has the bronze been glued to a piece of hardboard (Masonite) tempered on both sides. This change has not been evaluated, but will be used in 1970 testing.

4. Electrical Counters

Six electrical counters were used in the original P.C.A. Road Meter. The Iowa State Highway Commission Road Meter was built using ten counters for greater accuracy.

In testing adjacent sections, it was very time consuming to stop, record counter readings, back up and accelerate to 50 mph for starting the next section. To eliminate this, two banks of 10 counters were installed so stopping was unnecessary. A rotary switch is used to very simply switch from one bank to the other at 50 mph. In using two banks of counters, it is very important that both banks are of the same type and equal efficiency. Counters of the same type puchased at different times were found to have efficiencies that varied greatly and could not be used in the same unit.

Push button reset type counters are now being used, and they are much faster and more convenient than the original wind reset type.

5. Console

The original large console has been miniaturized and mounted with the counters, as can be noted in Fig. 3.

6. Electrical System

The Iowa State Highway Commission unit had twelve indicator lights originally and a switch to shut off every counter individually. In the modification (Fig. 3) there are only 10 lights and only counters one and two can be shut off individually. A two position 12 pole (two 6 pole wafers) rotary switch was installed for use of the two banks of electrical counters. A current electrical diagram is shown in Fig. 5.

7. Vehicle

In March, 1967, when the Road Meter was introduced to the Iowa State Highway Commission, the only vehicles with coil type rear springs owned by the Commission were 1967 Chevelle stationwagons. The unit was built, installed and experimental testing conducted (beginning June, 1967). This vehicle had springs of the proper strength and worked quite well. There were, however, two distinct disadvantages: it was too light and greatly affected by wind; if the wind was below 7 mph, the results were very good.

A request was made for a full size Ford for use as a Road Meter vehicle. Automobile production had been shut down for 1967, so one was purchased from stock of an Iowa dealer. This was a Ford Custom without air-conditioning. The springs were very weak and gave very poor results. In an effort to remedy this problem, double acting shock absorbers were installed (September, 1967). The double acting shock absorbers did not satisfy the problem. They detracted from the smooth working suspension of the coil springs, yielding undesirable repeatability. They also caused the

Variable wind effects if you drive with windows open sometimes and closed other times? May be a point for Air Conditioning!

Road Meter to work very poorly in cold weather. The conclusion was that double acting shock absorbers should not be used.

A 1968 Ford Custom 500 with power steering, power brakes and air-conditioning was obtained as a Road Meter car in March of 1968. This vehicle had the proper springing and functioned very well.

The Road Meters for 1970 are Ford Custom 500's with cruise control to maintain a constant speed.

Some testing was conducted to determine the proper springing constant. Using the 1968 Ford Custom, it appears that a spring constant of 160 lb./inch would be desirable. However, on other makes of vehicles this may have to be altered.

4.0 PROCEDURE

Upon introduction of the Road Meter in 1967, the Portland Cement Association had developed a correlation between the Chloe Profilometer and the Road Meter. This correlation was reduced to a semi-logarithmic curve for the determination of Present Serviceability Index. In the early development of the Road Meter, it was the feeling of some that the same curve could be used for all full size Fords. This is definitely not true, as even vehicles of the same model have somewhat different suspension. To be correct, every car must be individually correlated against the Chloe Profilometer. There are some vehicles that will have the same correlation. The Chloe Profilometer is considered the standard for the determination of Present Serviceability Index.

In addition to an annual spring correlation, the Road Meter should be re-correlated when installed in a new vehicle, when the suspension of the vehicle changes or when the Road Meter device is altered.

When the Iowa State Highway Commission began operating the Road Meter in 1967, it was to be used to evaluate both asphaltic concrete and portland cement concrete type pavements. For this reason, the decision was to correlate it on both AC and PCC pavements. Thirteen AC and seventeen PCC test sections of varying degrees of roughness were selected for the correlation.[5]

The Chloe was operated in the outside wheel track over the test sections that varied in length with the average being near one-half mile. The slope variance for each section was determined.

[5] Bunnag, Anuphan, "Iowa State Highway Commission's P.C.A. Type Road Meter", (1967)

The Road Meter was operated over each of the sections and the sum over length determined. The method of Road Meter operation is described in Appendix 3.

The original work by the Portland Cément Association was based on the assumption that the relationship between Chloe slope variance and Road Meter deviations per mile was a linear correlation ($Y = MX + B$).

The procedure discussed to this point was used by the Iowa State Highway Commission for the years of 1967 and 1968.

In May of 1969, the Chloe was operated in both the inside and outside wheel tracks in an effort to yield a better correlation. The AC pavements had never yielded a good correlation between the Chloe and Road Meter. One reason for this is that many AC pavements have an open texture due to some unsound aggregates popping out of the surface. The surface texture has a large effect on the determination of slope variance by the Chloe. In view of these facts, the AC test sections were eliminated from the correlation, leaving 33 PCC pavement sections (June, 1969).

In some cases it was very apparent that a straight line was not the best correlation of the points. Some type of curve would yield a better fit of the points. Again in an effort to yield a better correlation, a parabolic type fit was adopted in July of 1969 ($Y = CX^2 + MX + B$). As can be noted, if a straight line is the best fit, the parabolic curve will yield a straight line relationship when the first term becomes zero. In vehicles with weaker suspension, the parabolic fit is often the only correlation that will yield a reasonable Present Serviceability Index.

The correlation between Chloe Slope Variance and the summation of road-car deviations (sum/length) using the least square parabolic method was obtained by the statistical method shown in Appendix 4. The regression equation, derived from 33 PCC test sections, which were tested by Road Meter No 4, is:

$$\text{Chloe Slope Variance} = 4.176,472 + 0.005,636,619\ R + 0.000,000,662,544\ R^2$$

with correlation coefficient = 0.9802

R = Road Meter deviations per mile.

The line of equality and equation are shown in Fig. 7, the statistical functions for the least square parabolic method are shown in Table IV.

This correlation was substituted into the Present Serviceability Index equations for both PCC pavement and AC pavement. The equations in term of (R), are:

For Flexible Pavement:

$$PSI = 5.03 - 1.91 \log (4.176,472 + 0.005,636,619\ R + 0.000,000,662,544\ R^2) - 1.38\ \overline{rd}^2 - 0.01 \sqrt{c_1 + p} \quad \text{---------(1)}$$

For Rigid Pavement:

$$PSI = 5.41 - 1.80 \log (4.176,472 + 0.005,636,619\ R + 0.000,000,662,544\ R^2) - 0.09 \sqrt{c_2 + p} \quad \text{---------------------(2)}$$

The Present Serviceability Index equations for both PCC pavement and AC pavement are plotted on semi-logarithm paper in Fig. 8. These equations are excluding the deduction for cracking, patching and rutting.

The Present Serviceability Indexes measured by the Road Meter were determined using the curve of Fig. 8 as derived from Equation (2) and the PSI values were tabulated in Table V. The correlation was determined. The regression equation is:

PSI (Chloe Profilometer) = 0.105963 + 0.972,495 PSI (Road Meter)-----(3)

with correlation coefficient = 0.9812

Standard Error Estimate = 0.1004

The regression is shown in Fig. 9.

Statistical methods show that we could expect about 68% of data to fall within the error of ± 0.10, and about 95% of data to fall within the error of ± 0.20 as compared with the Present Serviceability Index measured by the Chloe Profilometer.

The repeatability was conducted by using nine individual PCC sections; each section was tested nine times.

The statistical figures included in Table VI support the good repeatability of the Road Meter.

5.0 REFERENCES

1. AASHO Road Test — "Pavement Serviceability and Performance", HRB Special Report 61E, (1962)
2. Carey, W.N., Jr., Huckins, H.C. & Leathers, R.C., — "Slope Variance as a Measure of Roughness and the Chloe Profilometer", HRB Special Report 73, (1962)
3. Brokaw, M.P., — "Development of the P.C.A. Road Meter, a Rapid Method of Measuring Slope Variance", Portland Cement Association (1966)
4. Brua, Philip R., — "Pavement Performance Information", Technical Bulletin No. 4, American Concrete Paving Association (1969)
5. Bunnag, Anuphan, — "Iowa State Highway Commission's P.C.A. Type Road Meter", (1967)
6. Carey, W.N., Jr. and Irick, P.E., — "The Pavement Serviceability-Performance Concept", HRB Bulletin 250 (1960)
7. Spiegel, Murray R., — "Theory and Problems of Statistics" (1961)

TABLE I

Comparison Between P.C.A. Road Meter of Portland Cement Association and Iowa State Highway Commission

Description	Original 1965 Portland Cement Association Road Meter	Iowa State Highway Commission P.C.A. Type Road Meter			
		May 1967-August 1967	Sept. 1967-Feb. 1968	March 1968-March 1970	April 1970
Flexible steel strand	Flexible nylon-covered braided fish leader	High test steel core fish leader 45 lb. test	High test steel core fish leader 60 lb. test	Nylon-covered aircraft cable 240 lb. test	Nylon-covered aircraft cable 240 lb. test
Contact Board	Formica	Plexiglass under Formica	Plexiglass under Formica	Plexiglass under Formica	Hardboard tempered both sides
Roller Slide Plate	Formica	Formica (2 piece)	Bakelite Plexiglass	Glass reinforced Delrin	Glass reinforced Delrin
Electric Counters	1 bank of 6 counters ITT General Controls CE-600	1 bank of 10 counters ITT General Controls CE-600	2 banks of 10 counters ITT General Controls CE-600	2 banks of 10 counters (CE 47AP4115)	2 banks of 10 counters (CE 47AP4115)
Automobile	1965 Ford Galaxie four-door sedan	1967 Chevelle stationwagon	1967 Ford Custom four-door sedan	1968 Ford Custom 500 four-door sedan, 840 lb. load capacity, power brakes and steering, air conditioning	1970 Ford Custom 50 four-door sedan 840 lb. load capacity, power brakes & steering, air conditioning
Shock Absorbers	Single acting	Single acting	Double acting	Single acting	Single acting
Speed Control	-	-	-	-	Equipped
Automotive Electrical Power	12 volts	12 volts	12 volts	12 volts	12 volts
Measurements	1/8" increments	1/8" increments	1/8" increments	1/8" increments	1/8" increments

Suspensin
GVW

(continued)

TABLE I (continued)

Comparison Between P.C.A. Road Meter of Portland Cement Association and Iowa State Highway Commission

Description	Original 1965 Portland Cement Association Road Meter	Iowa State Highway Commission P.C.A. Type Road Meter			
		May 1967-August 1967	Sept. 1967-Feb. 1968	March 1968-March 1970	April 1970
Type of Tire and Tire Pressure	7:75x15 tires with 25 psi & 4-ply nylon snow tires with 25 psi	7:75x14 tires with 25 psi (cold) and 28 psi (warm)	7:75x15 tires with 25 psi (cold) and 28 psi (warm)	7:75x15 tires with 25 psi (cold) and 28 psi (warm)	7:75x15 tires with 25 psi (cold) & 28 psi (warm)
Test Speed	50 mph.	50 mph.	50 mph.	50 mph.	50 mph.
No. of Passengers	One person or two	Two persons	Two persons	Two persons	Two persons
Testing Temperature	Above 15°F.	Above 15°F.	No significant effect above 30°F.	No significant effect above 0°F.	No significant effect above 0°F.
Wind Velocity	No significant effect up to 15 mph.	No significant effect up to 10 mph.	No significant effect up to 10 mph, but testing is permitted up to 15 mph.	No significant effect up to 10 mph, but testing is permitted up to 15 mph.	No significant effect up to 10 mph, but testing is permitted up to 15 mph.

TABLE II

Bill of Material

Item	Quantity	Description
1	20	Electrical counters, CE 47AP4115 General Controls ITT
2	1	Roller micro switch #BZ-2RQ181-A2, Division of Honeywell
3	13	Miniature bulb sockets, 12 with red jewels (L12 Red 95x57) 1 with green jewel (L12 Green 95x57)
4	2	Two position toggle switches
5	1	Single toggle switch
6	1	Vernier dial, Calrad VD-70
7	2	Beauchaine plug P-3315-CCT
8	1	Beauchaine socket S-3315-CCT
9	1	Beauchaine socket S-3315-AB
10	1	Beauchaine plug P-3312-CCT
11	1	Beauchaine socket S-3312-AB
12	1	Beauchaine plug P-3302-AB
13	1	Beauchaine socket S-3302-CCT
14	30'	Intercom wire, 9 pair (18 wires, stranded)
15	-	Miscellaneous plywood, masonite, aluminum frame and 1/4" and 1/8" channel
16	1	Chassis box fuse
17	50"	1/16" Nylon coated pre-formed galvanized aircraft cable (340 lbs. breaking strength)
18 A.	1	CTS Industrial Electronic Components T-80, 12 position
18 B.	2	CTS Industrial Electronic Components T-9, 6 pole, 2 position
18 C.	1	Kurz Kasch Knob BP-648-3L, black, 1/4" brass hole
19	1	9653J19 Spring
20	1	Miscellaneous tension spring
21	1	Glass reinforced Delrin

TABLE III

Source of Supply

1. Neuco Inc.,
4109 W. Lake St.
Chicago, Illinois 60624

Alternate:

Revere Electric Supply Co.
2501 W. Washington
Chicago, Illinois

2. Electrical Engineering & Equipment Company
1201 Walnut
Des Moines, Iowa

3,7,8,9, 10,11,12,13, 14,16,18. Mid-State Distributing Company
511 S. 3rd Street
Ames, Iowa

Alternate:

Electronic Supply Inc.
113 Kellogg Ave.
Ames, Iowa

4,5. Iowa State Highway Commission P & E

6. World Radio Lab
3415 W. Broadway
Council Bluffs, Iowa

15. Lumber Yard or Cabinet Makers

17,19,20. McMaster-Carr Supply Company
P.O. Box 4355
Chicago, Illinois 60680

21. Van Horn Plastics, Inc.
7990 University
Des Moines, Iowa 50311

TABLE IV

Summation of Correlation Tests and Summation of Statistical Functions for P.C.C. Pavements

Location of Test Run	Sect. No.	Length (Mile)	Chloe Slope Variance (Y)	PSI from Chloe	Road Meter Deviation (X)	XY	X^2	X^2Y	X^3	X^4
13th St.	1	0.473	9.22	3.88	607	5,596.54	368,449	3,397,100	223,648,543	135,754,665,601
	2	0.500	34.08	2.70	3,114	106,125.12	9,696,996	330,473,623	30,196,445,544	94,031,731,424,016
	3	0.500	25.58	2.94	2,808	71,828.64	7,884,864	201,694,821	22,140,698,112	62,171,080,298,496
	4	0.500	26.22	2.92	2,882	75,566.04	8,305,924	217,781,327	23,937,672,968	68,988,373,493,776
	5	0.473	9.26	3.88	891	8,250.66	793,881	7,351,338	707,347,971	630,247,042,161
I-35	6	0.473	9.87	3.80	924	9,119.88	853,776	8,426,769	788,889,024	728,933,458,176
	7	0.473	9.01	3.90	777	7,000.77	603,729	5,439,598	469,097,433	364,488,705,441
	8	0.473	8.14	4.00	614	4,997.96	376,996	3,068,747	231,475,544	142,125.984,016
	9	0.473	8.23	3.98	766	6,304.18	586,756	4,829,002	449,455,096	344,282,603,536
Co.Rd. "C"	10	0.519	9.38	3.85	1,009	9,464.42	1,018,081	9,549,600	1,027,243,729	1,036,488,922,561
	11	0.519	10.68	3.73	1,090	11,641.20	1,188,100	12,688,908	1,295,029,000	1,411,581,610,000
Co.Rd. "D"	12	0.500	8.87	3.91	855	7,583.85	731,025	6,484,192	625,026,375	534,397,550,625
	13	0.500	9.96	3.80	1,147	11,424.12	1,315,609	13,103,466	1,509,003,523	1,730,827,040,881
	14	0.500	10.62	3.73	1,002	10,641.24	1,004,004	10,662,522	1,006,012,008	1,008,024,032,016
	15	0.500	11.40	3.66	1,266	14,432,40	1,602,756	18,271,418	2,029,089,096	2,568,826,795,536
Co.Rd. "B"	16	0.500	10.65	3.73	867	9,233.55	751,689	8,005,488	651,714,363	565,036,352,721
	17	0.500	9.36	3.90	838	7,843.68	702,244	6,573,004	588,480,472	493,146,635,536
	18	0.500	10.08	3.78	994	10,019.52	988,036	9,959,403	982,107,784	976,215,137,296
	19	0.500	9.35	3.85	1,092	10,210.20	1,192,469	11,149,538	1,302,170,688	1,421,970,391,296
New US 30	20	0.473	9.83	3.80	790	7,765.70	624,100	6,134,903	493,039,000	389,500,810,000
	21	0.530	8.73	3.92	666	5,814.18	443,556	3,872,244	295,408,296	196,741,925,136
	22	0.473	8.36	3.97	519	4,338.89	269,361	2,251,858	139,798,359	72,555,398,321
Co.Rd. "E"	23	0.477	23.92	3.01	2,319	55,470.48	5,377,761	128,636,043	12,471,027,759	28,920,313,373,121
	24	0.477	30.16	2.81	3,543	106,856.88	12,552,849	378,593,926	44,474,744,007	157,574,018,016,801
	25	0.488	23.97	3.00	2,801	67,139.97	7,845,601	188,059,055	21,975,528,401	61,553,455,051,201
	26	0.488	25.29	2.95	3,172	80,219.88	10,061,584	254,457,459	31,915,344,448	101,235,472,589,056
Calhoun	27	0.610	5.80	4.36	372	2,157.60	138,384	802,627	51,478,848	19,150,131,456
	28	0.650	6.22	4.30	256	1,592.32	65,536	407,634	16,777,216	4,294,967,296
	29	0.650	5.34	4.49	256	1,367.04	65,536	349,962	16,777,216	4,294,967,296
	30	0.610	5.55	4.43	224	1,243.20	50,176	278,477	11,239,424	2,517,630,976
Greene	31	0.490	5.78	4.38	435	2,514.30	189,225	1,093,721	82,312,875	35,806,100,625
	32	0.530	5.88	4.36	151	887.88	22,801	134,070	3,442,951	519,885,601
	33	0.490	6.55	4.23	335	2,194.25	112,225	735,073	37,595,375	12,594,450,625
			411.34		39,382	736,846.49	77,784,074	1,854,716,919	202,145,121,448	589,304,767,391,198

TABLE V

Comparison between P.S.I. Measured by Chloe Profilometer
and by the Formula Obtained for I.S.H.C. Road Meter

Section No.	PSI (X) by Formula	PSI (Y) by Chloe Profilometer	X^2	Y^2	XY
1	4.03	3.88	16.24	15.05	15.64
2	2.86	2.70	8.18	7.29	7.72
3	2.95	2.94	8.70	8.64	8.67
4	2.93	2.92	8.58	8.53	8.56
5	3.82	3.88	14.59	15.05	14.82
6	3.79	3.80	14.36	14.44	14.40
7	3.88	3.90	15.05	15.21	15.13
8	4.03	4.00	16.24	16.00	16.12
9	3.90	3.98	15.21	15.84	15.52
10	3.75	3.85	14.06	14.82	14.44
11	3.69	3.73	13.62	13.91	13.76
12	3.84	3.91	14.75	15.29	15.01
13	3.64	3.80	13.25	14.44	13.83
14	3.74	3.73	13.99	13.91	13.95
15	3.59	3.66	12.89	13.40	13.14
16	3.83	3.73	14.67	13.91	14.29
17	3.85	3.90	14.82	15.21	15.02
18	3.75	3.78	14.06	14.29	14.18
19	3.69	3.85	13.62	14.82	14.21
20	3.89	3.80	15.13	14.44	14.78
21	3.98	3.92	15.84	15.37	15.60
22	4.12	3.97	16.97	15.76	16.36
23	3.10	3.01	9.61	9.06	9.33
24	2.74	2.81	7.51	7.90	7.70
25	2.96	3.00	8.76	9.00	8.88
26	2.86	2.95	8.18	8.70	8.44
27	4.28	4.36	18.32	19.01	18.66
28	4.42	4.30	19.54	18.49	19.01
29	4.42	4.49	19.54	20.16	19.85
30	4.45	4.43	19.80	19.62	19.71
31	4.20	4.38	17.64	19.18	18.40
32	4.56	4.36	20.79	19.01	19.88
33	4.32	4.23	18.66	17.89	18.27
	123.86	123.95	473.17	473.64	473.28

TABLE VI

Investigation of Repeatability of Iowa State Highway Commission

P.C.A. Type Road Meter

Test Section No.	Average PSI	Standard Deviation	Range	Coefficient of Variation (%)	BPR Rating
5	4.06	.077	3.92-4.14	1.91	Good
6	2.93	.050	2.83-2.98	1.70	Poor
8	2.99	.051	2.88-3.05	1.70	Poor
9	2.96	.033	2.89-3.00	1.11	Poor
10	3.81	.046	3.76-3.90	1.19	Good
11	3.85	.033	3.79-3.90	0.96	Good
12	3.99	.057	3.90-4.09	1.43	Good
13	4.01	.052	3.90-4.07	1.29	Good
14	3.91	.052	3.83-3.98	1.32	Good

Note: Present Serviceability Index does not include deduction for cracking, patching and rut depth.

Fig. 1 IOWA STATE HIGHWAY COMMISSION PCA TYPE ROAD METER VEHICLE

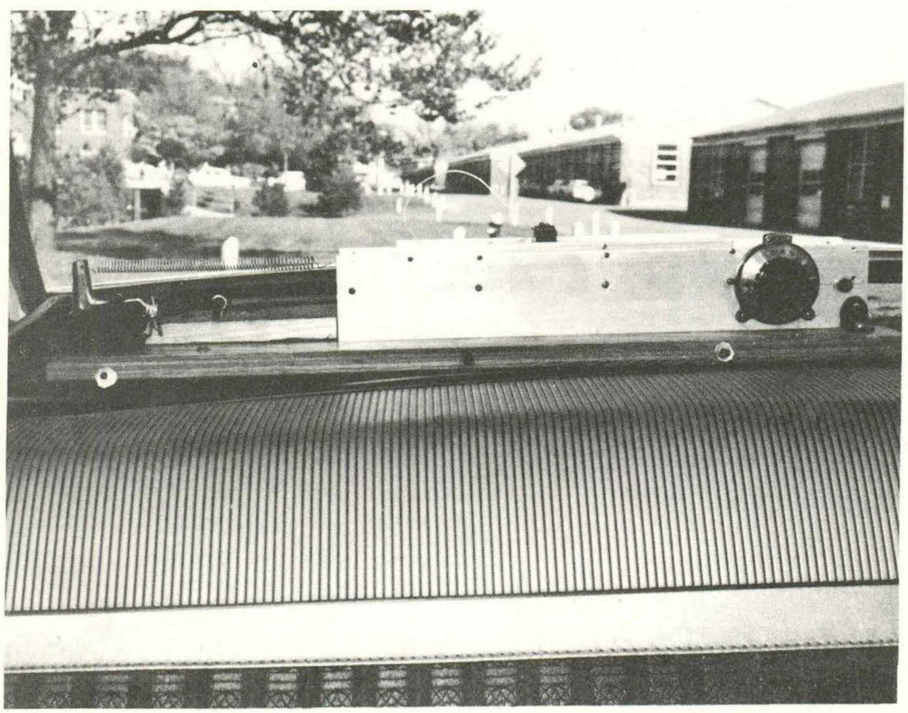


Fig. 2 FRONT VIEW OF CONTACT BOARD ASSEMBLY OF ROAD METER INSTALLED ON REAR DECK OF AUTOMOBILE

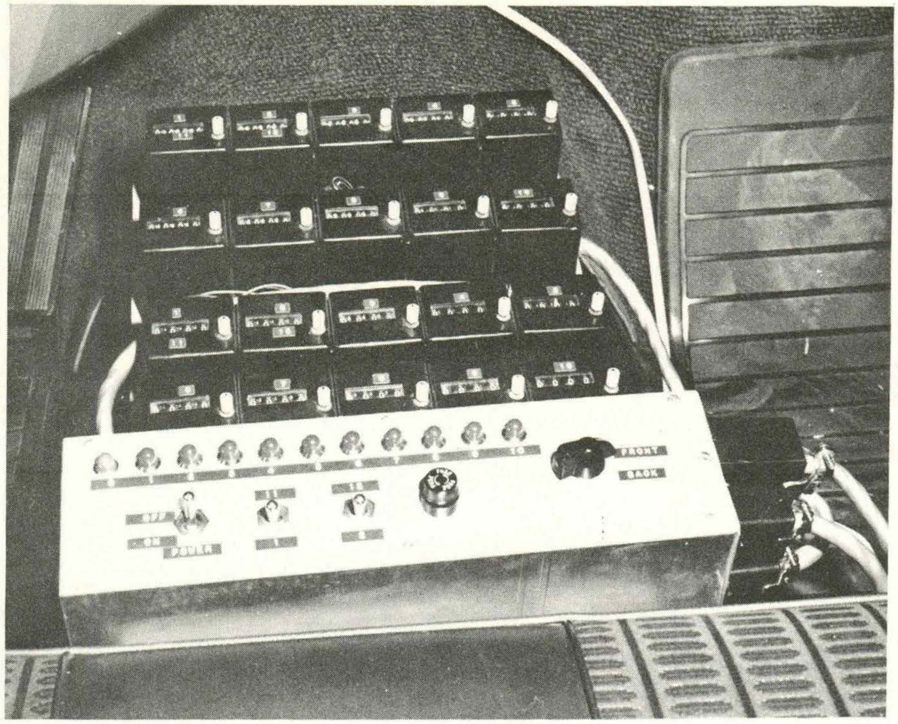


Fig. 3 ROAD METER CONTROL CONSOLE, SHOWING VISUAL INDICATORS AND SWITCHES, AND ELECTRIC COUNTERS RESTING ON FLOOR OF AUTOMOBILE

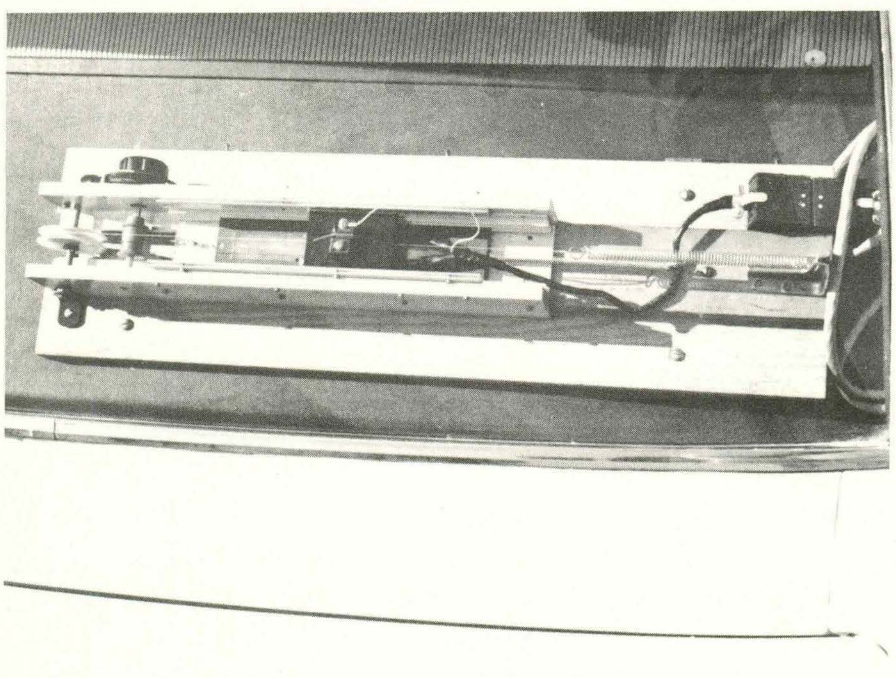


Fig. 4 TOP VIEW OF CONTACT BOARD ASSEMBLY OF ROAD METER INSTALLED ON REAR DECK OF AUTOMOBILE

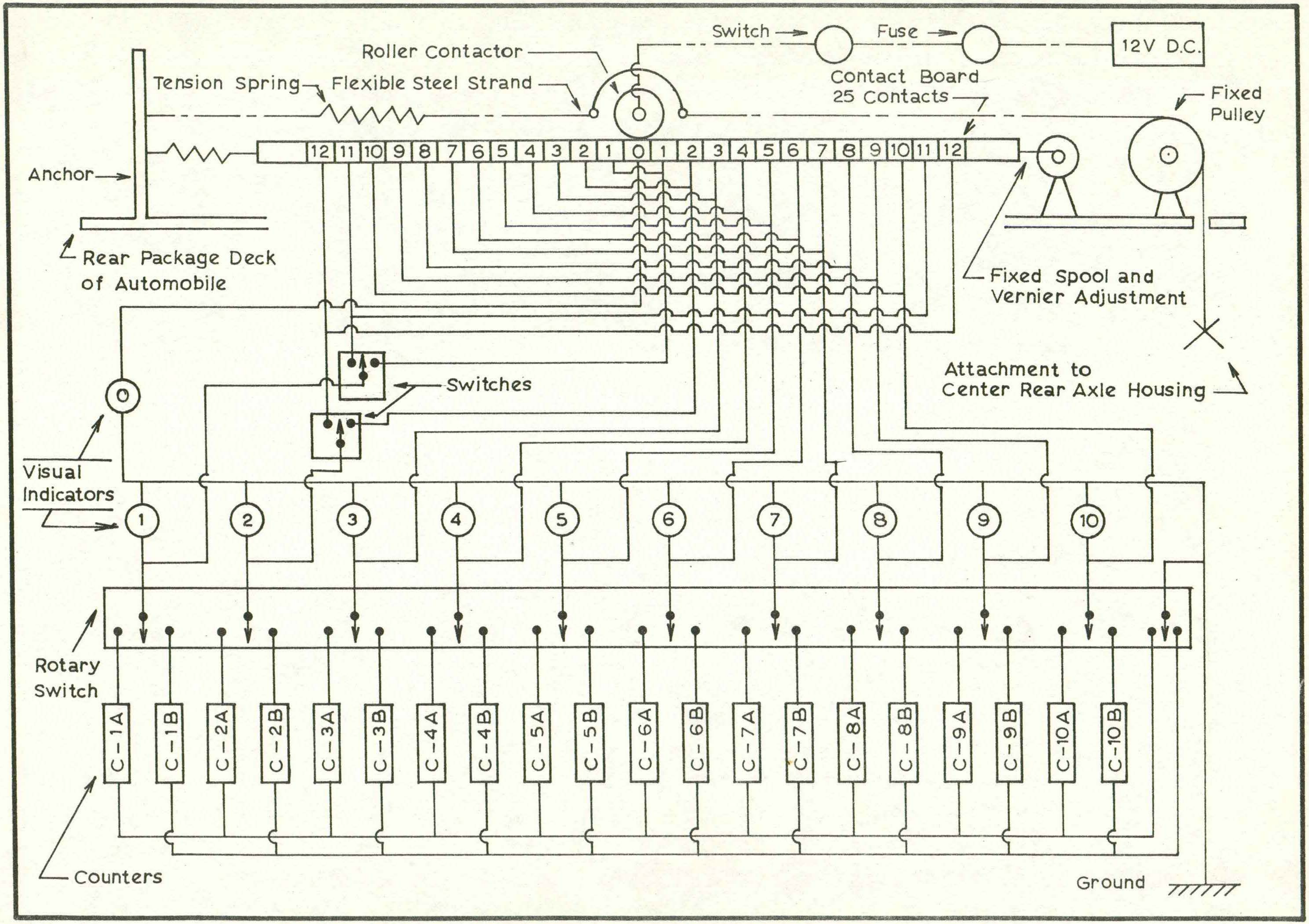
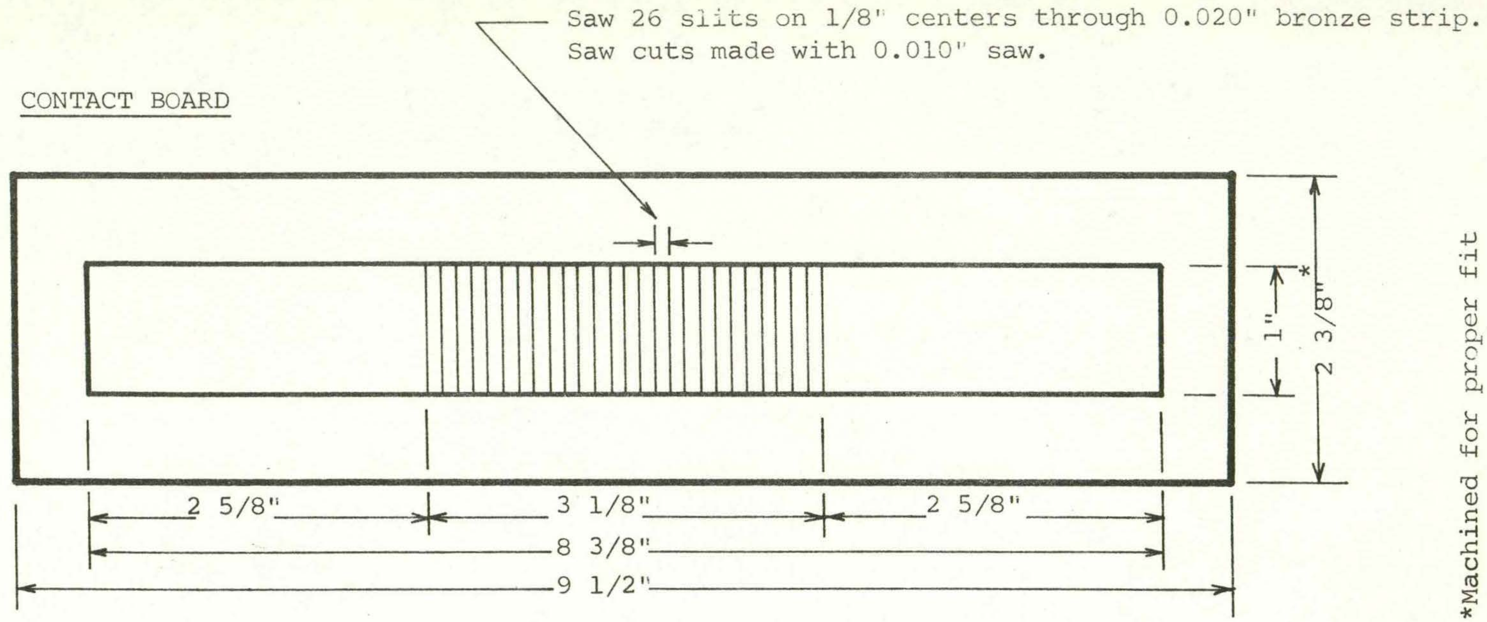
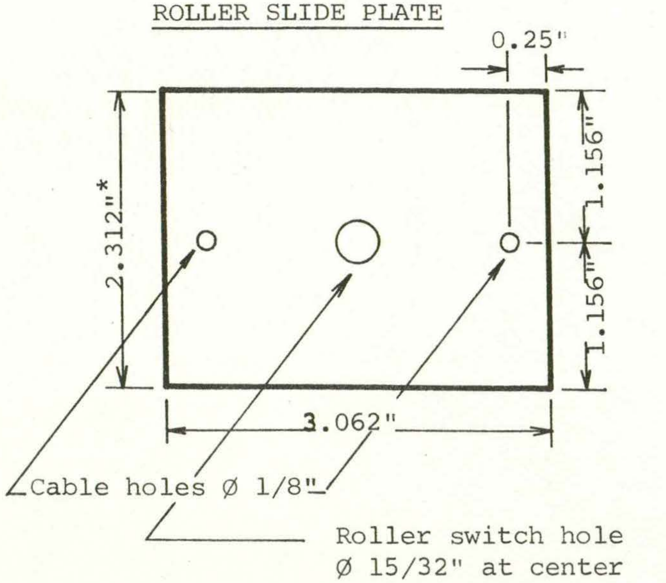


Figure 5 - Schematic Diagram of Mechanical and Electrical Features of Iowa State Highway Commission's P.C.A. Type Road Meter.





For roller slide plate use 1/8" thick glass reinforced delrin as indicated by drawing.

Note: For Contact Board

Material is double tempered 1/4" Masonite.
The 0.020" thick phosphor bronze strip is glued directly to the tempered Masonite using Pierce and Stevens Chemical Corp. Hybond/80 Multi-purpose contact adhesive as indicated by the above drawing.
Total thickness with bronze strip glued to the Masonite is approximately 0.260".
Machine cut the slits 1/8" on center through the bronze strip as indicated.
Drill holes 0.040" No. 60 drill at edge of bronze strip for attaching wires. Solder wire leads in holes.
Fill slits and secure wires using Epoxy Cement or glue after wires are soldered to bronze segments.
Sand off excess Epoxy to make good smooth contact for roller switch.

Figure 6 - Finished Dimensions of Contact Board and Roller Slide Plate.

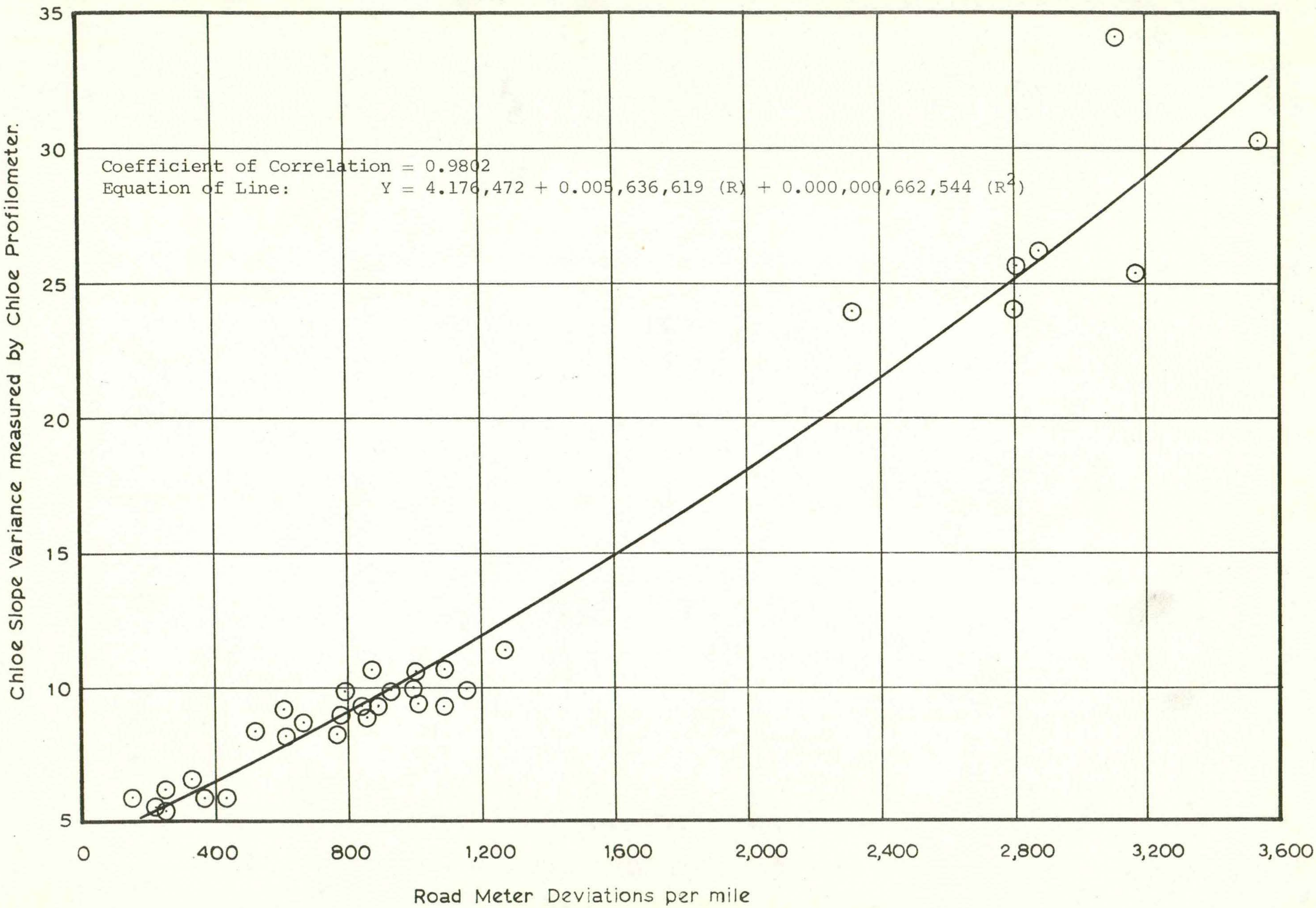


Figure 7 - Correlation between Chloe Slope Variance and Road Meter Deviations Per Mile Measured by I.S.H.C.'s PCA Type Road Meter.

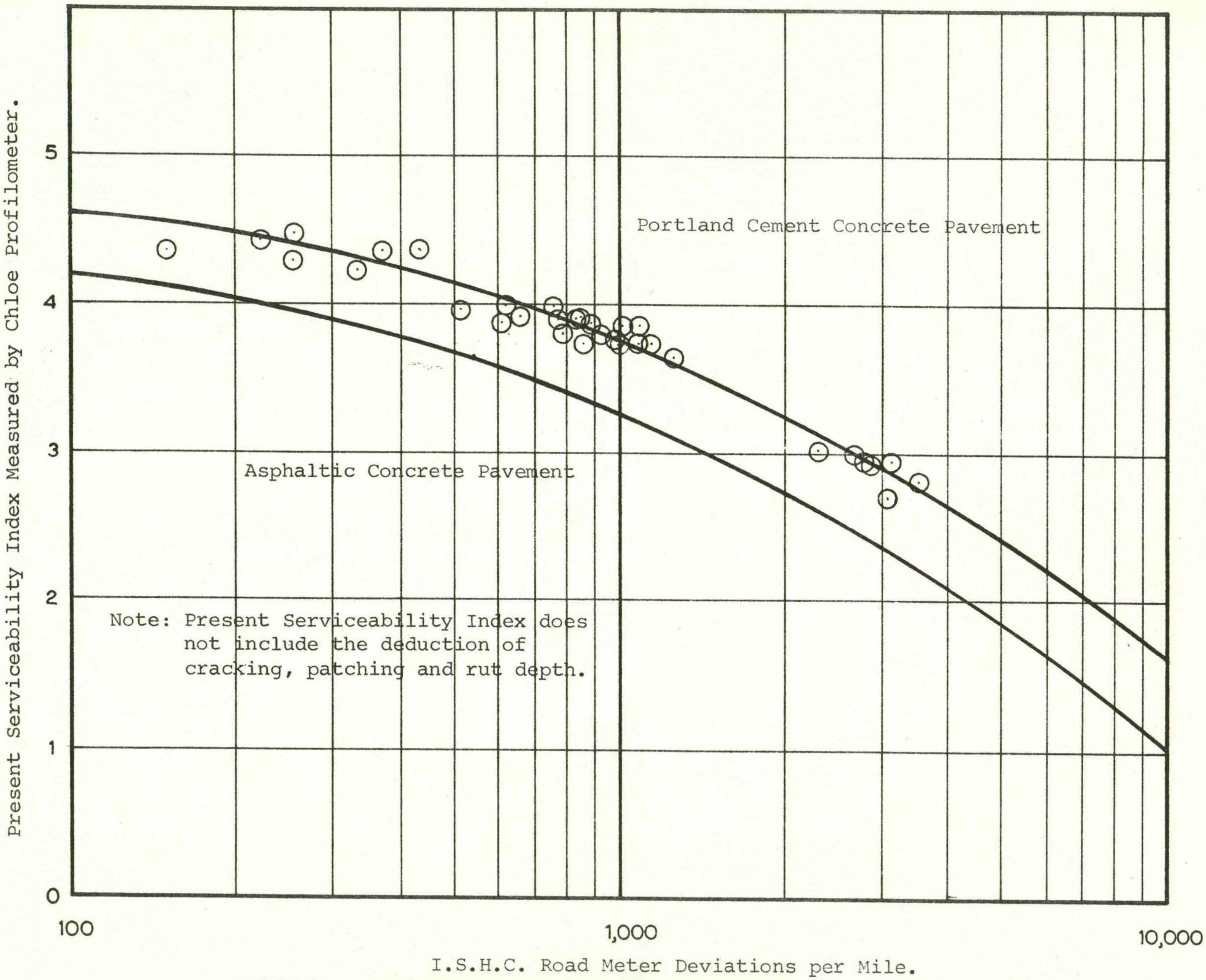


Figure 8 - Correlation Between Present Serviceability Index Measured by Chloe Profilometer and I.S.H.C. Road Meter Deviations Per Mile.

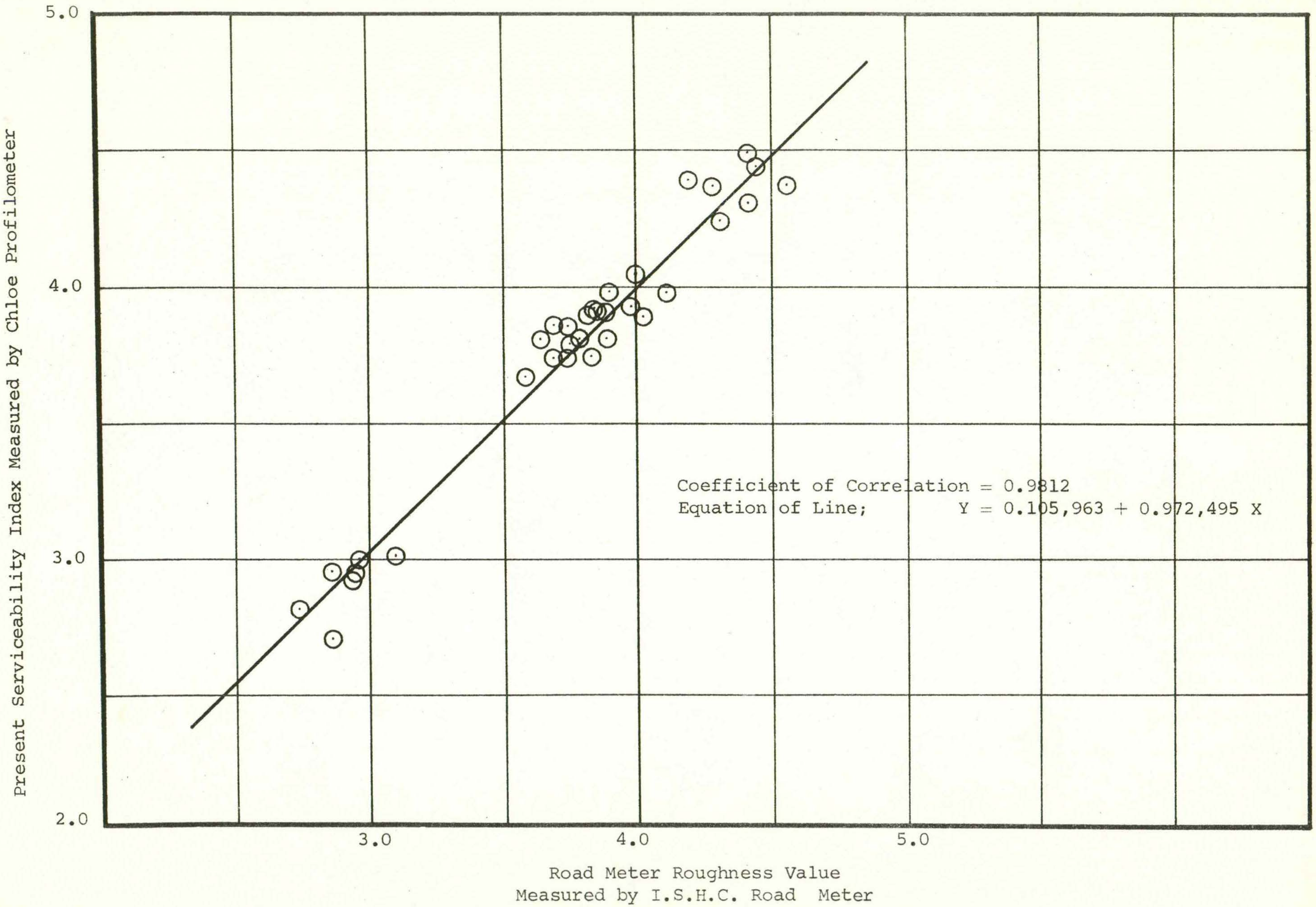


Figure 9 - Comparison of Index Measured by Chloe Profilometer and I.S.H.C.'s PCA Type Road Meter

APPENDIX 1

DEVELOPMENT OF THE PCA ROAD METER

Road Meter Theory

The PCA Road Meter measures the number of road-car deviations in ± 1/8 in. increments referenced to the standing position of the automobile. Numbers are accumulated in electric counters. Sum of squares of deviations, $\Sigma(R^2)$, has been correlated with Slope Variance from the Chloe Profilometer, as shown in the body of this report.

The method for reducing Road Meter data is shown below:

1. Basic data for sum of squares

Let a,b,c,d,e,f, ... = number of road-car deviations, corresponding to ± 1,2,3,4,5,6, ... eighths of an inch, respectively. Then,

$$\Sigma(D^2) = (1a + 4b + 9c + 16d + 25e + 36f + ...) /64 \quad (1)$$

or $\Sigma(R^2) = 64 \quad \Sigma(D^2)$

2. Composition of Road Meter counts

Because electric counters record once for a maximum deviation and twice for segment numbers less than the maximum, total recorded counts are:

Counter 1 (1/8 in.) = a + 2b + 2c + 2d + 2e + 2f + ...

Counter 2 (2/8 in.) = b + 2c + 2d + 2e + 2f + ...

Counter 3 (3/8 in.) = c + 2d + 2e + 2f + ...

Counter 4 (4/8 in.) = d + 2e + 2f + ...

Counter 5 (5/8 in.) = e + 2f + ...

Counter 6 (6/8 in.) = f + ...

3. Reduction of Road Meter counts to $\Sigma(D^2)$

If recordings shown in Road Meter counters 1, 2, 3, 4, 5, 6, ... are multiplied by the integers 1, 2, 3, 4, 5, 6, ... respectively, the following reduction and summation can be made:

Counter 1 = a + 2b + 2c + 2d + 2e + 2f + ...

Counter 2 = 2b + 4c + 4d + 4e + 4f + ...

Counter 3 = 3c + 6d + 6e + 6f + ...

Counter 4 = 4d + 8e + 8f + ...

Counter 5 = $5e + 10f + \ldots$

Counter 6 = $6f + \ldots$

$$\Sigma(D^2) = (a + 4b + 9c + 16d + 25e + 36f + \ldots)/64 \qquad (2)$$

Equation (2) = Equation (1)

4. Sample calculation

Road Meter count from one-mile survey of rigid pavement

Counter 1 = 348

Counter 2 = 180

Counter 3 = 40

Counter 4 = 14

Counter 5 = 7

Counter 6 = 2

Counter 7 = 0 (Extrapolated)

Composition of Road Meter count

Σ 7/8" Deviations = 0

Σ 6/8" Deviations = 2 - (2x0) = 2

Σ 5/8" Deviations = 7 - (2x2) = 3

Σ 4/8" Deviations = 14 - (2x2) - (2x3) = 4

Σ 3/8" Deviations = 40 - (2x2) - (2x3) - (2x4) = 22

Σ 2/8" Deviations = 180 - (2x2) - (2x4) - (2x22) = 118

Σ 1/8" Deviations = 348 - (2x2) - (2x3) - (2x4) - (2x22) - (2x118) = 50

Sum of squares of deviations

$\Sigma(6/8)^2 = 2 \times 36 = 72/64$

$\Sigma(5/8)^2 = 3 \times 25 = 75/64$

$\Sigma(4/8)^2 = 4 \times 16 = 64/64$

$\Sigma(3/8)^2 = 22 \times 9 = 198/64$

$\Sigma(2/8)^2 = 118 \times 4 = 472/64$

$\Sigma(1/8)^2 = 50 \times 1 = 50/64$

$$\Sigma(D^2) = 931/64 = 14.6 \qquad (1)$$

Direct reduction of Road Meter counts

Counter 1 = 348 x 1 = 348

Counter 2 = 180 x 2 = 360

Counter 3 = 40 x 3 = 120

Counter 4 = 14 x 4 = 56

Counter 5 = 7 x 5 = 35

Counter 6 = 2 x 6 = 12

$\Sigma(D^2) = 931/64 = 14.6$ (2)

or $\Sigma(R^2) = 931$

APPENDIX 2 (3)

DEVELOPMENT OF THE PCA ROAD METER

Derivation and Modification of Chloe Computing Formula Showing the Relation of Slope Variance and Sum of Squares of Chloe Vertical Deviations

Derivation of the Chloe computing formula is outlined on page 136 of Highway Research Board Special Report 73.

Equation 4b is restated, as follows:

$$\text{Chloe Slope Variance}/10^6 = (\tan 10')^2 \times (\Sigma Y^2/N) - (\Sigma Y/N)^2$$

Instead of computing slope variance of pavement surface, it is possible to calculate variance of vertical deviations (d) in a nine-inch gage length. Gage length is the distance between detecting wheels of the Chloe Profilometer.

Then equation 4b can be modified:

$$\text{Variance of Vertical Deviations} = 81 \times \text{Chloe Slope Variance}/10^6$$

Sum of squares of Chloe vertical deviations per mile is equal to variance multiplied by the number (N) of observations taken at six-inch intervals.

Then,

$$\Sigma(d^2) = 10{,}560 \times 81 \times \text{Chloe Slope Variance}/10^6$$

$$\Sigma(d^2) = 0.855 \times \text{Chloe Slope Variance}$$

Therefore,

$$\text{Chloe Slope Variance} = 1.17\ \Sigma(d^2)$$

APPENDIX 3

Method of Determination of Road Meter Roughness Value by Iowa State Highway Commission's P.C.A. Type Road Meter

SCOPE:

This test method is used to determine the Road Meter Roughness Value (RMRV) by P.C.A. Type Road Meter. The Road Meter Roughness Value or longitudinal profile value is used to determine the Present Serviceability Index (P.S.I.). The Present Serviceability Index was developed by the American Association of State Highway Officials (AASHO) Road Test as an indicator of the ability of a pavement to serve the traveling public and an objective method of highway evaluation.

The P.C.A. Type Road Meter was developed by a Portland Cement Association (P.C.A.) engineer in 1965. The Iowa State Highway Commission constructed a P.C.A. Type Road Meter in 1967 with slight modifications.

A. APPARATUS

1. P.C.A. Type Road Meter (electro-mechanical device installed in conventional passenger automobile).
2. Wind velocity gauge.
3. Tire pressure gauge.
4. Slide rule.

B. TEST RECORD FORMS, CONTROL SECTIONS AND MAPS

1. Road Meter worksheet (Form 921).
2. Laboratory final report form (Forms 915 and 922).
3. The description of test sections.
4. State and county maps.
5. Road Meter Roughness Value Curve (Semi-logarithmic).

C. PERSONNEL

Two men required: one assigned to drive while the other operates the counters and makes calculations.

D. CALIBRATION

The Road Meter Roughness Value equation is derived from the equations of the AASHO Road Test using the correlation between the CHLOE Profilometer and the Road Meter. The relationship between the CHLOE Slope Variance and the (ΣR) Road Meter deviations per mile (Sum/Length) shall be correlated using the least square parabolic method ($Y = CX^2 + MX + B$).

E. TEST PROCEDURE

1. Drive the Road Meter cars for a minimum of 15 miles before testing is begun.
2. Operate the Road Meter cars in a careful, legal, concientious manner.
3. Operate the Road Meter cars for a maximum of 20 miles between "zeroing" operations. Obtain the zero setting as follows:
   a. Turn the vernier or slide leader to obtain a green (0) indicator.
   b. Turn the vernier dial clockwise until the 0 and 1 visual indicators light together and observe the vernier reading.
   c. Turn the vernier dial counter clockwise until the 0 and 1 visual indicators light together and observe the vernier reading.
   d. Add the two observed reading, divide by two and set the vernier to the obtained value. Verify the green light obtained.
4. Start the testing vehicle far enough from the beginning of the test section to insure adequate distance for acceleration to the standard test speed of 50 mph. Turn the main switch to the ON position as soon as the front wheels pass the start of the test section and turn it off at the end of the test section. Take odometer readings at the same times for measuring the test section length.

the entire car should be in the section!

5. Turn the main switch off just before crossing railroad tracks and bridges and then on again after crossing; omit this length.
6. Record the counter values on the Road Meter worksheet and calculate Road Meter deviations per mile.
7. Conduct a second test when the visual indicators show a possible malfunction. Average the two values if the difference of these two runs is less than 10%. If they are not, make a third run and void the erroneous test.

Good Luck!

8. Use the road meter deviations per mile value to determine the Road Meter Roughness Value from the curve.

F. PRECAUTIONS

1. Maintain tire pressure at 25 psi cold, 28 psi warm. If any tire alignment or balancing problems are noted, have them corrected.
2. Suspend testing if the wind is 15 mph or greater. Tests may be conducted with winds above 15 mph if the Road Meter is operated in the same direction as the wind. Use good judgement in regard to gusty winds.

always!

Note the comment on page 6.

3. Operate the Road Meter with the windows closed except for short periods to converse or signal.
4. Disconnect the flexible steel strand if traveling more than 30 miles to the next test site.
5. Disconnect the flexible steel strand and put the plug in the hole (in the trunk compartment), if driving on dirt or gravel roads. they have lots of those in Iowa.
6. Do not use solvent or cleaning fluids on the contact board. Clean the contact board normally with a dry cloth; use a very fine emery cloth only in case the dry cloth will not clean the board satisfactorily. Blow the metallic grindings off after using emery cloth, and then clean the board with a dry cloth. No
7. Keep the Road Meter cars in a neat, orderly condition.
8. Service the Road Meter cars at 2,000 mile intervals.

G. ROAD METER ROUGHNESS VALUE CALCULATIONS

The field work sheet provides a place to note the road number, county, laboratory number, year built, date tested, date reported, contractor, project number, location, weather, wind, temperature, test personnel, road surface type, control section and direction. The method of calculation is as follows: the summation of counts from Counter No. 1 x 1, Counter No. 2 x 2, Counter No. 3 x 3, etc., is divided by the length (in miles) of the test run to obtain the Sum/Length value. This Sum/Length is then used to determine the Road Meter Roughness Value (RMRV) from the semi-logarithmic curve. The example for recording and calculating is shown in Fig. (a).

H. REPORTING RESULTS

The final report for all testing results is practically the same as the field work sheet. The only differences are that the Present Serviceability Index is reported, and it includes the deduction for cracking and patching. Examples of the final report are shown in Fig. (b) and (c).

IOWA STATE HIGHWAY COMMISSION
Materials Department
AMES LABORATORY

ROAD METER No. 7 WORKSHEET

Road No. I-35 County Story Lab. No. RM
Year Built Date Tested 7-29-69 Date Reported
Contractor Hallet Construction Co. Project No. I-IG-35-4(12)103
Location From Polk Co. line to Jct. New US 30

Weather Clear Wind NE 5-8 mph Temp. 71 °F
Speed 50 mph. Test Personnel Dalbey & Robinson Surface P.C.

C.S. 85-1210	S.T. P.C.	D. 0-NB				
End	13.87					
Start	3.90					
Length	9.97					
Deduct	0.05 (1 Bridge)					
Length	9.92					
1	4031	4031				
2	1794	3588				
3	412	1236				
4	91	364				
5	25	125				
6	6	36				
7	1	7				
8	-	-				
9	-	-				
10	-	-				
Sum		9387				
Sum/L		946				
RMRV		4.00				

C.S. 85-1210	S.T.	D. 0-SB				
End	24.17					
Start	14.15					
Length	10.02					
Deduct	0.05 (1 Bridge)					
Length	9.97					
1	4075	4075				
2	1740	3480				
3	403	1209				
4	132	528				
5	60	300				
6	27	162				
7	12	84				
8	4	32				
9	1	9				
10	-	-				
Sum		9879				
Sum/L		990				
RMRV		3.89				

C.S.	S.T.	D.				
End						
Start						
Length						
Deduct						
Length						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Sum						
Sum/L						
RMRV						

C.S.	S.T.	D.				
End						
Start						
Length						
Deduct						
Length						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Sum						
Sum/L						
RMRV						

Notes

C.S. = Control Section. S.T. = Surface Type D. = Direction

Form 922

Fig. (b)

IOWA STATE HIGHWAY COMMISSION

Materials Department

AMES LABORATORY

ROAD METER REPORT

Road No. I-35 County Story Lab. No. RM 9 - 522

Year Built 1965 Date Tested 7-29-69 Date Reported 8-15-69

Contractor Hallett Construction Co. Project No. I-IG-35-4/12/103

Project Length (Miles) 10.03 Surface Type PC

Location From Polk County line north to junction New US 30.

Weather Clear Wind NE 5-8 mph Temperature 71°

Test Personnel Dalbey & Robinson

	N Outside Bound Lane	S Outside Bound Lane
Length Tested	9.97	10.02
Length Deducted 1 Bridge	0.05	0.05
Net Length Tested	9.92	9.97
Road Meter Roughness Value	4.00	3.90

Average Road Meter Roughness Value	3.95
Deduction for Cracking, Patching and Rut Depth	0.05
Present Serviceability Index	3.90

Fig. (c)

IOWA STATE HIGHWAY COMMISSION
Materials Department
AMES LABORATORY

1969 Present Serviceability Index Summary for Story County (85)

Date Reported 8-15-69 Lab. Nos. RM 9 - 522

Lab. No. RM	Control Section	Road No.	Length (Miles)	Surface Type	Dir. & Lane	Road Meter Roughness Value	Winter 1968-69 Ded. for Cracking Patching	Present Service-ability Index
522	85-1210	I-35	10.03	PC	ONB	4.00	0.05	3.95
					OSB	3.95	0.05	3.90

Deductions for cracking and patching were calculated on a 2 lane roadway basis.

APPENDIX 4

Statistical Calculations

1. Least Square Parabolic Form:

$$Y = CX^2 + MX + B$$

2. Normal Equations:

$$\text{I.}\quad \Sigma(y) = BN + M\Sigma(X) + C\Sigma(X^2)$$

$$\text{II.}\quad \Sigma(XY) = B\Sigma(X) + M\Sigma(X^2) + C\Sigma(X^3)$$

$$\text{III.}\quad \Sigma(X^2Y) = B\Sigma(X^2) + M\Sigma(X^3) + C\Sigma(X^4)$$

where:

N = Number of samples

X and Y = Observed values of data

3. Coefficient of Correlation:

$$\bar{Y} = \frac{\Sigma Y}{N}$$

$$Yest. = B + M(X) + C\ (X)^2$$

$$\text{Total Variation} = \Sigma(Y - \bar{Y})^2$$

$$\text{Explained Variation} = \Sigma(Yest. - Y)^2$$

$$\text{The Correlation Coefficient} = \sqrt{\frac{\text{Explained Variation}}{\text{Total Variation}}}$$

4. Standard Error of Estimate:

$$S_{Y \cdot X} = \sqrt{\frac{\Sigma Y^2 - B\Sigma Y - M\Sigma XY - C\Sigma X^2Y}{N}}$$

THE IOWA STATE HIGHWAY COMMISSION

. 515-232-7250 . AMES, IOWA 50010

JOSEPH R. COUPAL, JR.
Director

H. E. GUNNERSON
Chief Engineer

August 31, 1970

Mr. K. H. Dunn, Research Engineer
Division of Highways
Department of Transportation
304 N. Randall Avenue
Madison, Wisconsin 53700

Dear Karl:

Enclosed is a copy of the report number R-226-A, which concerns modifications and improvements made on the PCA road meter by laboratory personnel in our Materials Department.

We made brief, individual skid test correlations with Missouri, Minnesota, Nebraska, and Illinois. A report has been started, but we haven't yet received the test data from Illinois. I'll make a note to send you a copy of the report.

Your experience with an ultrasonic cleaner for asphalt extraction is very similar to ours. We used our cleaner for a while as a pre-treatment prior to reflux extraction, but finally decided that the slight improvement in time was not worth the effort.

I attended the HRB Western Summer Meeting, although I had not originally planned to do so. A young man from our office wrote a short report on bridge deck cracking which was accepted for the meeting. Shortly before the meeting, he resigned to accept other employment, so I went to Sacramento in his place.

The papers on pavement evaluation were well received. I don't recall any particular discussions of them, except regarding Brokaw's on the PCA road meter. Brokaw raised a question about the need to include cracking and patching in calculating serviceability. My greatest personal interest was generated by Hudson's paper on the compatability of pavement evaluation methods and equipment.

Sincerely,

Steve

S. E. Roberts
Research Engineer

SER:mkr
Enclosure